E
O
S

ELECTRO-OPTICAL SYSTEMS, INC. Pasadena, California

2

PROPOSED PROGRAM FOR THE EXTENSION OF SOLAR CONCENTRATOR DEVELOPMENT WORK INITIATED UNDER CONTRACT NAS 7-10

Prepared for

Jet Propulsion Laboratory
Pasadena, California

EOS Proposal 61-824 Rev. A 5 October 1961

Prepared by

Staff of the Advanced Power Systems Division

Approved by

J. Neustein

J. Neustein
Manager, Advanced Power Systems Division

This document contains information proprietary to Electro-Optical Systems, Inc., and should be protected within the interpretation of ASPR Clause 3.109.

ELECTRO-OPTICAL SYSTEMS, INC. PASADENA, CALIFORNIA

ABSTRACT

This proposal, prepared by the Advanced Power Systems Division of Electro-Optical Systems, is for the extension of work initiated under Contract NAS 7-10. The proposed extension includes work in three areas related to the development of lightweight solar concentrators.

Backing structure studies

Advanced studies of nickel, copper and chromium electroforming

Advance coating studies

TABLE OF CONTENTS

1. INTRODUCTION

This document presents a proposed extention to the research and development work accomplished under Contract NAS 7-10. The ultimate goal of this type of work is the following:

> The development of large, lightweight solar energy concentrators having performance characteristics suitable for effective utilization with high temperature power generators such as thermionic converters.
>
> These collectors shall have durable, highly reflective surface coatings, adequate structural rigidity to withstand all expected environmental conditions, and an advanced structural concept optimized for minimum weight consistent with the above mentioned considerations as well as handling and packaging requirements.

Work accomplished under the present contract has made significant advances toward this goal. This document presents a proposed extension to this work which will bring the developmental status of solar concentrators even closer to this desired goal.

In as much as no program can be all inclusive, it is to be understood that the above goal for optimized solar concentrators lies within the following framework:

a. The basic technique for concentrator fabrication is the electroforming process.

b. The program will consider only materials which are easily platable from aqueous solutions and which have adequate structural characteristics for concentrator application. These materials are primarily nickel and copper.

On the basis of its experience to date, as well as information available from the literature, Electro-Optical Systems feels that the electroforming process using either nickel or copper offers the best possibility toward the achievement of the above goal. Although other processes or materials may be potentially superior, their successful utilization would depend upon extensive further research and development work.

The general goal will be achieved through the satisfaction of the following specific objectives:

a. Determination of best diameters for solid (non-segmented) mirrors on the basis of mission power requirements, converter efficiencies, launch vehicle envelope, payload packaging considerations, ground handling considerations, and mirror structural integrity.

b. Determination of the best approach when power requirements are greater than that which can be satisfied by a single solid mirror. Possibilities include multiple solid mirrors, ground-assembled segmented mirrors, and segmented mirrors automatically unfurlable in space.

c. Development of the optimum type of mirror rigidizing structure consistent with the requirements of Items a and b.

d. Specification of all plating and fabrication parameters for both nickel and copper in order to assure reproducible deposits of the highest possible quality and with optimum physical properties.

e. Development of highly reflective mirror coatings which will be sufficiently durable to withstand all ground handling operations as well as long term service in space.

1.1 Present Status

At the conclusion of the present phase of Contract NAS 7-10, the following accomplishments will have been made:

a. Plating procedures to assure high-quality, high-yield plating of nickel mirror skins and structural components.

b. Preliminary specification of copper plating procedures.

c. Development of detailed design and fabrication techniques for front torus supported mirrors.

d. Preliminary results on advanced mirror coatings.

e. Preliminary results on advanced concentrator structural techniques.

f. Demonstration, on a small scale (24" diam), of techniques suitable for fabrication of large masters.

1.2 Expected Status at Conclusion of Next Phase

At the end of the proposed extension to Contract NAS 7-10 the following technical status is expected:

a. Plating procedures for assuring high-quality, high-yield deposits of both nickel and copper will be completely specified.

b. At least one superior mirror structural technique, allowing nearly complete diameter utilization, will be demonstrated, and its structural integrity will be verified by environment testing.

c. Advanced mirror coatings, adequate for ground handling and cleaning, and sufficiently durable to withstand extended space missions, will be developed.

Technical results obtained on the proposed extension should be sufficient to allow a development program for larger mirrors to be undertaken with a high degree of confidence. It is expected that a decision will be forthcoming during the extension program regarding the best type and size of larger mirrors. This decision will be based on technical results from this program as well as information from JPL concerning mission and power requirements.

1.3 Remaining Work to Satisfy Overall Goal

In addition to the work to be accomplished in the present phase and the proposed extension of Contract NAS 7-10, the following additional tasks remain to be accomplished in order to achieve the general goal described in Sec. 1:

a. A suitable full-scale master must be fabricated and demonstrated.

b. Full-scale mirrors must be fabricated from this master. They must incorporate the optimum plating conditions, type of structure, and coatings developed earlier in the program. The mirrors must be thoroughly proof checked both optically and structurally.

In addition it may be necessary to build facilities for performing necessary operations such as application of vacuum deposited mirror coatings.

1.4 Program Summary

The first task is the study of improved backing structures for electroformed mirrors. The rim torus support already demonstrated has proved suitable for mirrors up to five feet in diameter. However, size increases and weight reduction will necessitate more sophisticated structural approaches.

Improvement of the available techniques for electroplating copper, nickel and chromium occupy the second phase of the program.

Copper in particular requires further development. It is known that a very high quality, hard, durable form of copper can be obtained by electrodeposition. Reliable bath controls for insuring such a deposit are not yet available. Criteria for ascertaining the proper plating parameters and bath composition are urgently needed to make copper electroformed mirrors practical.

The development of durable, highly reflective mirror surface coatings suitable for electroformed concentrators is the final objective of the proposed program. Many different approaches toward achievement of suitable coatings have been suggested. The more promising will be evaluated on a small scale basis. The better coatings will then be applied to larger mirrors and evaluated in regard to reflectivity, adherence to substrate, resistance to scratching and chemical attack, and resistance to space environmental conditions.

The proposal will be concluded with a statement of work, program schedule and program organization.

2. PROPOSED PROGRAM

2.1 Backing Structure Studies

Previous efforts on the NAS 7-10 contract have yielded a wealth of information on concentrator support structures. To date two types of support structures have received the major attention:

a. Rim mounted torus - this support consists of a thin-wall electroformed torus mounted on the outside of the concentrator and integrally attached to the concentrator skin during the skin forming process.

b. Monocoque support - this consists of a thin shell with a somewhat greater radius of curvature than the reflector skin attached to the reflector skin at the periphery.

Based on previous experience, EOS is quite positive of the possibility of improving both these support structure techniques, as well as the necessity for comparative evaluations by the several important criteria governing concentrator structures, to determine the optimum application of each of these techniques. Other support structure configurations, as outlined below, should also be investigated to determine their relative merits for future space applications. The following subsections outline the program to be pursued in extending the state of the art in this area of solar concentrator technology.

2.1.1 Evaluations of Thin Shell Structures

An evaluation of the optimum techniques for supporting thin shell structures will be continued. At least the following types of supports will be considered:

a. Torus

b. Solid monocoque

c. Monocoque with lightening holes

d. Radial stiffening members

e. Various combinations of the above.

In evaluating the structural techniques at least the following parameter variations will be considered:

a. Variations in skin and support structure thickness

b. Location of support structure attachment to reflector skin

c. Location of external reflector supports on structural members

d. Moduli of supports

e. Resonant frequencies

f. Methods of backing attachment.

This evaluation will provide a portion of the technical basis for determining the optimum sizing for larger concentrators. It will be based, largely, on the experimental studies described below.

2.1.2 Small Scale Experimental Studies of Support Structures

The evaluation of advanced structural concepts will begin with small scale studies of various types of structures. At least five parabolic reflectors, approximately 17 inches in diameter will be fabricated to demonstrate techniques.

The following critical areas will be studied to determine the optimum combination of parameters for concentrator backings:

a. Backing master:

(i) Fabrication

(ii) Methods of master removal after plating

b. Methods of support structure attachment:

   (i) Surface activation and attachment by electroforming

   (ii) Wire encapsulation technique

c. Structural characteristics of various structural concepts with emphasis on physical testing to determine stiffness.

d. Effects of intentionally using tensile or compressive plating stresses in structures.

The reflectors made in this phase of the program will be made available to the coating study (see Sec. 2.3) as required.

2.1.3 Fabrication of Five Foot Diameter Reflectors

At least two 5-foot diameter reflectors will be fabricated utilizing the two most promising support structure techniques, as determined from 2.1.2 above. The purpose of this fabrication will be to provide a basis for scaling laws as well as to gain the requisite experience in expanding these techniques to larger structures. These two reflectors will be subjected to environmental testing at the Jet Propulsion Laboratory. EOS personnel will be responsible for organizing the tests from a technical standpoint, and will assist substantially in performing the test work. It is understood that JPL will make available the necessary testing machines and mounting fixtures. The reflectors will be optically evaluated both before and after environmental testing to determine their capability of withstanding the launch environment. This will yield the requisite information on comparative performance of the backing structure in larger sizes as well as determine the resonant frequencies at this diameter. These two reflectors will also be made available to the coating study (see Sec. 2.3).

In addition, at least two more 5-foot diameter mirrors will be fabricated and destructively tested by mechanical loading, shock, or vibration to determine ultimate strength capabilities. Following these tests the mirrors will be sectioned to determine thickness uniformity, and selected pieces may be given physical properties tests.

In order to make possible the fabrication of advanced structures, as well as to improve the general quality of plating, certain specialized tools and fixtures will be constructed, including:

a. A device to allow continuous rotation of the entire mirror assembly during plating.
b. Handling fixtures to improve the ease and safety of handling and working on the mirror after parting.
c. Contoured, or otherwise specially shaped, anodes and masks.
d. Special mandrels or master extensions for maximizing the useful area of the mirror.

2.2 Advanced Studies of Nickel, Copper and Chromium Plating

Previous program efforts by Electro-Optical Systems in the electroforming of nickel and copper have resulted in the production of replicas of higher optical quality, lower stress level, and lower weight than had been possible with the previous electroforming state of the art. Although the capabilities of nickel plating have been brought to a highly advanced status, there is still some area for improvement as outlined below. Existing experience with copper is somewhat more limited. The previous efforts in nickel, however, point out very clearly the specific goals and objectives of a successful electroforming research program and will allow the avoidance of many of the pitfalls encountered during the nickel electroforming development. The chromium plating efforts at Electro-Optical Systems have been much more modest. However, it appears desirable to perform additional research into its plating properties for the purpose of providing a protective overcoating for electroformed nickel or copper parts. It appears that the intrinsic stress levels and brittleness of chromium are such that extreme difficulties might be encountered in attempting to form an entire part directly from chromium. The program and program objectives for these advanced studies are outlined below.

2.2.1 Program Objectives

The objectives of this phase of the program will include, but not be limited to, the following:

a. Improvement of the physical properties of lightweight electroformed shell structures of nickel and copper. Important physical properties include hardness, tensile strength, modulus of elasticity, and uniformity of thickness, and back surface finish. A specific objective of this work is to increase the knowledge of copper plating techniques and controls to a level approaching that of nickel.

b. Stress reduction and control and monitoring of stress levels during plating for nickel and copper.

c. Development of techniques for monitoring plating solution additive concentration during plating and development of technique for continually replenishing solution additives during plating (particular emphasis on copper).

d. Investigation of chromium protective overcoatings for nickel or copper mirrors.

2.2.2 Program

The program will consist of several interrelated and overlapping elements to yield the objective outlined above. Specifically the program elements will include:

a. Small scale sample plating and stress tests - these will be carried out in somewhat the same manner as in previous programs. However, techniques utilizing continuously monitored strain gauges mounted in solution will allow determination of stress during the actual plating operation and its control during plating. Samples to be fabricated will include small thin strips, small (6 inch) diameter mirrors and medium (17 inch) diameter reflectors.

b. Testing of physical properties of plated samples - these physical properties will include those outlined in 2.2.1 above. Special testing devices will be constructed where required in order to measure physical properties of interest. Where possible, samples will be taken from actual concentrator structures which have been environmentally tested.

c. Fabrication of structural parts - specific structural parts including typical support structures, mirror skins, etc., will be fabricated to gain experience which is more directly applicable to the fabrication of useful hardware.

d. Fabrication of 5-foot diameter reflectors based on these investigations - at least one 5-foot diameter mirror will be formed from copper using a technique which represents the most advanced state of development achieved under this program. The mirror will be both optically and environmentally tested. At least one additional 5-foot copper mirror, or major segment thereof will be built and destructively tested.

2.3 Advanced Coating Studies

The practicality and utility of solar concentrators for space applications depend to a large extent on the ability to provide and maintain durable, highly reflective surface coatings. The methods which have been developed in the optical industry for coating glass optical elements are not always suitable for metallic reflectors because of the following considerations:

a. Presence of surface oxide layers on metal mirrors

b. Different adhesion characteristics as compared with glass

c. Presence of sensitizing layers on electroformed mirrors

d. Diffusion of metal substrate materials through reflective coatings.

The objective of this portion of the proposed program is to develop satisfactory methods for coating large solar concentrators with durable, highly reflective surface layers. The following types of coatings and materials are of interest on this program in connection with the electroformed concentrators:

a. Parting Layer - To allow removal of plated mirror from master (silver, gold, copper, silicones)

b. Sensitizing Layer - For use with non-conductive masters (aluminum, chromium, silver, gold, copper)

c. Adhesion Layer - To firmly bond coating to substrate (silicon monoxide, chromium, copper, nickel)

d. Antidiffusion Layer - To prevent substrate material from diffusing through reflective layer (silicon monoxide)

e. Reflective Layer - Which may be a multilayer interference type (aluminum, silicon monoxide, chromium, silver, aluminum oxide, titanium dioxide)

f. Protective Layer - To prevent abrasion and chemical attack of reflective layer (silicon monoxide, aluminum oxide, titanium dioxide).

These types of coatings cannot be treated independently since one physical layer may serve the function of two or more types of coatings (e.g., chemical silver may serve as both the sensitizing and parting layers). Furthermore, the functions of these layers are so inter-dependent that it would not be wise to consider them separately. The objectives of the advanced coating studies will be achieved by a seven-part program. The first four parts will deal primarily with small flat surface samples. Parts five and six will involve the demonstration of selected coatings on actual mirrors (which will be made available from other phases of the proposed program). The last portion of the program will present considerations involved in the selection of facilities to coat large concentrators.

2.3.1 Problems Related to Substrate and Master Characteristics

Electroforming can only be accomplished using a master which is electrically conductive. This requires that the master either be metal or that it be coated with a thin layer of metal to make it conductive. Most of the current and near future work in electroformed concentrators will involve glass or plastic masters. The conventional method of sensitizing these masters is by a chemically deposited layer of silver. This layer adheres to the electroformed shell upon parting. This technique has disadvantages. The softness of the silver layer is an obstacle to the application of a highly adherent overcoating. If left unprotected, the silver rapidly corrodes. The silver cannot be conveniently removed, because its back surface (that which is adjacent to the nickel) is not sufficiently reflective. Several possible methods of overcoming these disadvantages will be investigated on the proposed program, including:

a. Development of durable reflective coatings for chemically deposited silver

b. Development of vacuum deposited parting sensitizing layers for electroformed mirrors, which can be stripped from the mirrors after parting

c. Development of metallic sensitizing layers which adhere to the master

d. Development of a highly reflective chemical silver layer which can be stripped.

These items will be investigated using small-scale surface samples. In connection with these items, the following additional considerations will be evaluated:

a. Effect of substrate material (plastic, glass, metal, etc.) on the choice of parting sensitizing layer
b. Pre-sensitization of surface of non-conductive master prior to application of metallic sensitizing layer
c. Measurement of coating adherence.

In Sec. 2.3.4, another method will be presented for alleviating the problems associated with the use of chemical silver: the predeposition of coatings on the master prior to electroforming.

2.3.2 Surface Coatings for Higher Reflectivity

Pure metals such as aluminum and silver provide fairly high reflectivity throughout the useful solar spectrum. However, even higher reflectivities may be obtainable by using mixtures of metals or by interference techniques. This portion of the program will have as its objective the specification of surface coatings for highest average reflectivity for solar energy, consistent with the requirements for good adhesion and resistance to abrasion, chemical attack, and space environmental degradation. Fortunately, some of the most promising interference-type coatings provide their own protective surface layers (see Sec. 2.3.3). At least the following coatings will be considered:

a. Vacuum deposited silver
b. Vacuum deposited aluminum
c. Interference coatings made up of aluminum and silicon monoxide
d. Interference coatings made up of aluminum, aluminum oxide, and

titanium dioxide (the latter two coatings being obtained by anodizing). The reflectivities of these and any other coatings which appear promising will be measured.

2.3.3 Coating Durability Considerations

Coatings must have adequate adherence to the substrate material and they must withstand such degrading influences as ground handling, cleaning, attack from corrosive gasses in the atmosphere, and attack from various space environmental factors. In all cases, some type of transparent protective layer must be provided because the metals aluminum and silver are susceptible to either physical abrasion or chemical degradation. Fortunately, some of the dielectric layers used in interference coatings provide adequate protection. This portion of the program will involve at least the following steps:

a. Specification of suitable protective coatings for each type of reflective coating
b. Development of specialized test equipment for measurement of coating adherence
c. Measurement of the adherence of various types of coatings
d. Measurement of coating abrasion resistance
e. Measurement of coating chemical inertness
f. Estimation of the effects of space environmental conditions
g. Specification of ground handling and surface protection procedures

h. Specification of cleaning procedures and development of specialized cleaning equipment.

2.3.4 Mechanics of Coating Deposition

Two general types of problems are involved in the application of coatings to electroformed mirrors:

a. Order in which coatings are deposited

b. Uniform coverage over large areas.

Many advantages may accrue from predeposition of all coatings on the master prior to electroforming. If this can be done successfully, a finished mirror will result upon parting (except for removal of the parting layer, which is a simple chemical operation). The feasibility of this technique has been proven by small scale studies accomplished at other laboratories. Its usefulness for large area concentrators has yet to be demonstrated. One of the main obstacles to its successful application is that of providing uniform coating thicknesses over large convex surfaces. This portion of the program will consider analytically the problems involved in assuring uniform coverage. On small scale surface samples, the feasibility of predeposition of coatings for electroformed mirrors will be demonstrated.

2.3.5 Demonstration of Selected Coatings - Small Mirrors

The most favorable coatings obtained as a result of the four previous program steps will be demonstrated by application to small mirrors developed in other parts of this program (described in Sec. 2.1 and 2.2 of this proposal).

2.3.6 Demonstration of Selected Coatings - Large Mirrors

The one or two best coatings will be applied to large mirrors developed in other sections of this program, if suitable coating facilities are available.

2.3.7 Facilities Considerations

Application of advanced surface coatings to large solar concentrators will require special facilities and coating machines. The last step in the coating studies will be to prepare a list of specifications for the coating equipment required to apply the types of coatings selected as most promising. A list of potentially suitable coating facilities in the United States will be drawn up and presented, if any such facilities are found to exist.

3. STATEMENT OF WORK

The contractor will conduct, on a best-effort basis, an extension to Contract NAS 7-10, which is a research and development program aimed at improving the state of the art of lightweight solar concentrators. The program extension will be accomplished in a period of 10-months and will include, but not be limited to, the following specific items of work:

3.1 Backing Structure Studies

a. Evaluation of thin shell structures in order to provide a basis for determining optimum size of large mirrors.

b. Small scale experimental studies of support structures including fabrication of at least five representative mirrors approximately 17 inches in diameter. These studies shall include:

(i) Backing master considerations

(ii) Support structure attachment methods

(iii) Physical evaluation of various backing structure concepts

(iv) Effects of tensile or compressive plating stresses on characteristics of backing structure.

c. Fabrication of at least two 5-foot diameter mirrors which demonstrate the most promising techniques. At least two additional 5-foot mirrors will be fabricated and destructively tested to determine ultimate strength capabilities.

d. Fabrication of special tools and fixtures required for development of advanced structures, including:
   - (i) Rotator
   - (ii) Handling fixture
   - (iii) Specially shaped anodes and masks
   - (iv) Special mandrels and master extensions.

e. Optical and structural testing of small and large mirrors. Vibration testing will be accomplished at JPL using JPL-supplied testing machines and mounting fixtures. EOS personnel will be responsible for test planning and will assist substantially in conducting tests.

3.2 <u>Advanced Studies of Nickel, Copper, and Chromium Plating</u>

a. Small scale studies regarding:
   - (i) Improvement of physical properties of nickel and copper mirrors
   - (ii) Reduction and control of plating stress in nickel and copper mirrors
   - (iii) Development of techniques for monitoring additive concentrations in plating solutions
   - (iv) Protective chromium overcoatings for nickel and copper mirrors.

   An objective of this work is to increase the knowledge of copper plating techniques to a level approaching that of nickel.

b. Physical testing of plated samples. Special testing devices will be constructed to measure important physical properties.

c. Fabrication of structural components.

d. Fabrication of at least one 5-foot diameter mirror which demonstrates the most promising techniques. At least one additional 5-foot diameter mirror, or major component thereof, will be fabricated for destructive testing.

e. Optical and structural testing of small and large mirrors (see Sec. 3.1 e).

3.3 Advanced Coating Studies

a. Small scale studies

(i) Study of problems related to substrate and master characteristics

(ii) Surface coatings for high reflectivity

(iii) Coating durability considerations including development of devices for measuring coating adherence and for mirror cleaning

(iv) Mechanics of coating deposition.

b. Demonstration of selected coatings on small mirrors fabricated in other phases of the program.

c. Demonstration of selected coatings on large mirrors fabricated in other phases of the program.

d. Recommendations concerning facilities for coating large concentrators.

3.4 Reports

a. Monthly Letter Reports, briefly describing the status of technical progress on the program (deliverable 15 days after the completion of each monthly reporting period, except for the fifth monthly reporting period).

b. Interim Summary Report, describing in detail all technical progress on the program during the first five months (deliverable 15 days after the completion of the fifth month, and in lieu of the fifth Monthly Letter Report).

c. Final Technical Report, describing in detail all technical results of the program (deliverable 30 days after completion of technical work on the program. Technical work on the program will be completed 10 months after contract initiation.)

3.5 Other Deliverable Items

a. Mirrors fabricated to demonstrate structural or materials developments will be deliverable upon completion of fabrication and testing, but specifically on or before completion of technical work on the program (10 months from contract initiation). The following items are deliverable:

(i) Five small mirrors (approximately 17 inches in diameter) which demonstrate advanced structural concepts.

(ii) Two 5-foot mirrors which demonstrate advanced structural techniques

(iii) One 5-foot mirror which demonstrates advanced copper plating techniques.

5. PROJECT ORGANIZATION

The main project responsibility will be in the Engineering Development Department (L. Springer, Manager; M. Pichel, Associate Manager) of the Advanced Power Systems Division (J. Neustein, Manager). Project Supervisor will be Marlowe Pichel. Most aspects of the program will be performed within the laboratories of the Engineering Development Department, with technical assistance from other members of the Advanced Power Systems Division.

BIOGRAPHICAL SKETCHES

JOSEPH NEUSTEIN

Dr. Neustein is Manager of the Advanced Power Systems Division of Electro-Optical Systems, Inc.

Prior to this position Dr. Neustein was with the Aeronutronic Division of the Ford Motor Company where he was Manager of Engine Research in the Space Technology Operation. His work there, which concerned rocket research, resulted in several classified technical publications. He was co-designer of a two-stage high altitude chaff-dispensing rocket system. For three years Dr. Neustein was affiliated in supervisory capacities with the US Naval Ordnance Test Station in Pasadena, at first as section head of the Thrust Producing Mechanisms Section, then as head of the Turbomachinery Branch where he participated in program planning of technical work for the Underwater Ordnance Department, and finally as head of the Hydrodynamics Research Branch where he guided a staff of about twenty engineers, mathematicians, and supporting personnel.

Between 1943 and 1951 Dr. Neustein was with the National Advisory Committee for Aeronautics, Lewis Flight Propulsion Laboratory, in Cleveland. As an aeronautical research scientist he was responsible for programs in jet engine component research.

Dr. Neustein obtained his B.S. in Mechanical Engineering in 1943 from the University of Pittsburgh. Graduate studies included work at Case Institute of Technology, Western Reserve University, and California Institute of Technology. His Ph.D. in Mechanical Engineering was awarded by Caltech in 1957 for "Experiments at Low Reynolds Numbers with Airfoils and with Axial Flow Turbomachinery." He is a member of the Institute of the Aerospace Sciences and the American Rocket Society. He was elected to the following honorary societies: Sigma Xi, Pi Tau Sigma, Sigma Tau and Phi Eta Sigma.

LEE M. SPRINGER

Mr. Springer is a design specialist and project supervisor of the solar collector models program.

For over six years prior to his joining Electro-Optical Systems, Mr. Springer was head of the Design Group of the Engineering Center of the University of Southern California, where he was involved in subsonic, supersonic, and low density wind tunnel design and fabrication, materials testing, cryogenics, cryopumping, and the design and building of general research facilities. He has taught day and night classes in the Engineering School, starting with an Engineering and Science Management Defense Training course in Tool and Die Design which he originated in 1943.

He has been responsible for numerous projects to design and build a wide variety of equipment such as road building machinery, automatic high speed fabrication and assembly dies, oil drilling rig elevators, lightweight high horsepower gear boxes for a production military aircraft self-powered multidecked aircraft service stand, aircraft landing gear components, automatic multiple spindle drilling machine, large hydraulic presses, small hydraulic cylinders for aircraft use, heat exchangers of several types, automatic welding and furnace brazing tooling, many jigs, fixtures and dies for various production runs, small special tools for orthodontic use, instruments for electronic industry, automatic orthopedic symptometer, dies for plastics, toys and metal novelties.

Mr. Springer graduated from Los Angeles City College in 1936 with a major in aeronautical engineering. He then attended California Institute of Technology majoring in mechanical engineering. From time to time he has taken courses at the University of Southern California and the University of California at Los Angeles.

Mr. Springer is a member of ASTM and ASTME and is a registered Professional Mechanical Engineer in the State of California.

MARLOWE A. PICHEL

Mr. Pichel is manager of the Space Structures Laboratories of the Advanced Power Systems Division, which is engaged in the development of advanced design and fabrication techniques for extremely light-weight solar energy concentrators for space applications.

Mr. Pichel majored in mechanical engineering and industrial design at Muir College in Pasadena. From 1950 to 1952 at Jet Propulsion Laboratories he was engaged in small-scale rocket tests which included ignition lag and thermal decomposition studies. In 1952 he and four others formed the new Propellants Research Group of Olin-Mathieson Chemical Corporation in Niagara Falls, New York, where he became project engineer of a monopropellant system development program and authored a number of papers on system design. He is a member of the American Rocket Society and the American Ordnance Association.

In 1954, Mr. Pichel returned to California to become president and general manager of Consolidated Research and Development Corporation, a small manufacturing company engaged in the development, production and marketing of various items of a commercial nature. In 1958, Consolidated was purchased by Wham-O Manufacturing Company of San Gabriel and operated as a separate division. Mr. Pichel assumed management of that division during its integration with the parent company. Subsequently, he was responsible for the organization and operation of subsidiary companies, initially in Chicago and later in Frankfurt, West Germany, which produced and marketed many of the parent company's products.

DONALD H. McCLELLAND

Mr. McClelland is Manager of the Energy Conversion and Regulation Department in the Advanced Power Systems Division. He is responsible for research programs in the areas of fluid mechanics, heat transfer, spectral selectivity, the optical and structural aspects of solar energy concentrating systems, and the development of lightweight optical components and photovoltaic power generators.

For approximately two years prior to coming to Electro-Optical Systems, Inc., he was on the staff of the Controls and Auxiliaries Section of the Aeronautical Systems Department at Space Technology Laboratories, working on the analysis of rocket propulsion and control systems, missile auxiliary power supplies, and flight test analysis, lightweight solar collectors, and space power systems.

Mr. McClelland received his A.B. in Physics from the University of Kansas in 1954, and his Master's Degree in Aeronautical Engineering from Cornell in 1956. He was a Summerfield Scholar at the University of Kansas and a John McMullen Graduate Scholar at Cornell. He was elected to membership in Phi Beta Kappa, Sigma Pi Sigma, Delta Phi Alpha, and the Institute of Aeronautical Sciences, the American Rocket Society, the British Interplanetary Society, and the American Association for the Advancement of Science.

DONALD E. STEWART

Mr. Stewart joined Electro-Optical Systems. Inc. in August 1961 as an electrochemical engineer interested in energy conversion and regulation systems. He is currently engaged in the development of optical replicas and solar collectors.

Mr. Stewart received his Bachelor of Science in Applied Chemistry from the California Institute of Technology in 1952, his Master of Science in Chemical Engineering from the same school in 1953, and his Master of Business Administration from Stanford Graduate School of Business in 1958. He was elected to Sigma Xi, received the General Petroleum Fellowship, 1952-53, and the Frank Diamond Scholarship in 1957-58.

At Standard Oil Co. of California he did preliminary pressure vessel and heat exchanger design on the isophthalic acid plant. In the Army Chemical Corps he served with the Inspection Department of the Materiel Command as a chemical engineer. At Industrial Hard Chrome Plating Corporation he served as technical director in charge of electroforming, research and development, and the Kanigen electroless nickel operation. Duties encompassed the application of electrochemical and engineering design to a wide range of missile, atomic, computer and optical problems.

His publications include, "Volumetric Properties of n-Hexane."